VEHICULAR TRIP ESTIMATION IN URBAN AREAS

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by

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&

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TO:	K. B. Woods, Director Joint Highway Research Project	July 22, 1964
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FROM:	H. L. Michael, Associate Director Joint Highway Research Project	Project: C-36-54DD

The attached Technical Paper "Vehicular Trip Estimation in Urban Areas" was presented at the last Annual Purdue Road School at one of the seperate sessions of the Traffic Engineers. It has been authored by Messrs. J. J. Schuster and H. L. Michael of our staff.

The paper is a summary of the research on travel pattern characteristics conducted by Mr. Schuster under the direction of Professor Michael. The report gives nine regression models which were developed for use in synthesizing travel pattern studies in cities in standard metropolitan statistical areas of less than one million population, eight of which are in Indiana.

The paper is presented to the Board for approval for publication in the Proceedings of the Road School and for the record.

Respectfully submitted,

H. L. Michael, Secretary

HLM:sat

Attachment

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Technical Paper

VEHICULAR TRIP ESTIMATION IN URBAN AREAS

by

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and

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July 22, 1964

INTRODUCTION

A standard metropolitan statistical area is defined (except in New England) as a county or a group of contiguous counties which contain at least one city of 50,000 inhabitants or more or "twin cities" with a combined population of at least 50,000. In addition to the county, or counties, containing such a city or cities, contiguous counties are included in a standard metropolitan area if, according to certain criteria, they are essentially metropolitan in character and are socially and economically integrated with the central city. In New England, towns and cities rather than cities and counties are the units used in defining standard metropolitan statistical areas (1).*

In 1960 there were 212 standard metropolitan areas in the United States of which 188 had a population less than one million. Table 1 shows the number of these areas in each of four ranges of population. Of the 180 million people in the United States in 1960, approximately 63 percent lived in those 212 metropolitan areas. The location of the standard metropolitan statistical areas are shown in Figure 1. The projected population of the United States for 1980 is 245 million people with 75 percent of them living in urban areas. These urban inhabitants will perform millions of miles of daily travel within the city in which they live and a major share of it will be made by automobile.

The optimum location and design of urban transportation facilities require a reasonably accurate estimate of the usage of each facility

* Numbers in parentheses refer to entries in the List of References.

in the design hour of the design year. Good estimates of this usage appear to be possible from a knowledge of the current travel patterns of the city. Consequently many cities have conducted travel pattern studies, commonly known as origin-destination surveys. Such a study provides information on the current travel patterns of an individual city and techniques are available to project the patterns to a future year. These studies, however, are time-consuming and expensive. Moreover, past studies indicate a similarity of travel patterns in cities of similar size and it is generally acknowledged that travel of urban residents has many similar characteristics.

Synthesis of these travel patterns from characteristics of the city and its inhabitants has been the subject of considerable recent study. Each of these studies, however, has generally been performed in only one city and the resulting techniques have not been entirely satisfactory when applied to another city.

Several of the cities in the standard metropolitan statistical areas have had recent transportation studies, including origin-destination. The possibility existed, therefore, of analyzing the results of several of these studies in the hope that techniques and models for synthesizing the travel patterns of cities of similar size in these areas could be developed.

The purpose of this research was to develop a method for synthesizing urban travel patterns through an evaluation of various factors which affected travel patterns in fourteen urban areas.

The study included an investigation of travel pattern characteristics in standard metropolitan statistical areas less than one million population.

This population classification was chosen because of the possible homogeneity in the factors affecting transportation facilities. Statistical analyses of data from the fourteen cities were made to evaluate correlations in urban travel pattern characteristics. Urban vehicular trip patterns, peak-hour travel and design hour volume, truck trips, and traffic generation of the central business district were among the characteristics investigated.

STATISTICAL ANALYSIS PROCEDURES

One of the most useful tools available to the planner is statistics. Particularly in the field of trip prediction, the techniques of simple regression, multiple regression, and model evolution are extremely useful. One important statistical measure is the square of the correlation coefficient. This provides a measure of the amount of variability of a dependent variable that is explained by the independent variable or variables. This explained variation (R^2) is referred to as the coefficient of determination in regression analysis.

The evolution of models from data using multiple regression procedures allows the acquisition of maximum information from collected data. Without the use of a computer, model evolution would be impossible due to the enormous amount of calculations. Two procedures available for evolving a model are the "build-up" and the "tear down." The former method involves finding the simple correlation coefficients among all independent and dependent variables and then selecting the variables to go into the model. Independent variables which do not add enough explained variation of the dependent variable to warrant

their inclusion in the model are not included. To examine the amount
of additional explained variation, the F-test is generally utilized.

There is more flexibility in the choice of variables to be
included in the final model in the "tear-down" method. At first, all
independent variables are placed in the model. Then subsets, usually
consisting of those independent variables which have the largest
simple correlations with the dependent variable and the smallest
simple correlations with the independent variables, are tested. There
may be reason to retain certain variables in the model and this may
be accomplished by including them in the subsets. Many subsets are
tried and a comparison is made on the fractional amounts of variation
in the dependent variable explained by the independent variables
before a model is finally decided (2).

One element that must be considered in model evolution is the use
of the final model. In planning studies it is often necessary to
predict future trips from future land use areas. It is necessary to
assume that the factors that affect present day trips will also
affect future trips if a model evolved from present day trip data is
used for trip prediction. Preference may therefore be given to certain
variables which are expected to have similar influences today and in
the future even though the highest correlation coefficient may not
be attained.

The general model evolved through multiple regression is of the
following form (2):

$$Y_i = B_o + B_1 X_{1i} + B_2 X_{2i} + \cdots B_k X_{ki} + e_i$$

where:

Y_i = ith observed value of the dependent variable

B_o = parameter

B_i = parameter. $i = 1, 2, \cdots k$

X_{ji} = the ith observation of the jth independent, fixed

variable, which could be an interaction such as X_1X_2, X_1^2,

X_2^2, etc. $j = 1, 2, \cdots j \cdots k$ and $i = 1, 2, \cdots n$.

The estimating model is of the following form:

$$y_i = b_o + b_1 x_{1i} + b_2 x_{2i} + \cdots b_k x_{ki} + e_i.$$

Where:

b_o = least square estimate of B_o

b_i = least square estimate of B_i

e_i = the ith residual.

To use the above models the three basic assumptions outlined below must be made for tests of significance and confidence intervals.

a. The independent variables are fixed and measured without error.

b. For a set of independent variables, the dependent variable is normally and independently distributed.

c. For any set of independent variables the variances of the dependent variables are homogeneous.

URBAN TRAVEL PATTERN DEVELOPMENT

General

For the location and design of a transportation facility a knowledge of the volume of vehicles using the facility at the design hour is imperative. The usual procedure for securing an estimate of such volumes is through an analysis of the travel patterns of the city as determined by an origin-destination survey. Such a survey, however, may not be available or possible of completion before the location of a freeway and its

interchanges are necessary. It may be possible, furthermore, to develop methods for estimating the travel patterns of a city from travel pattern characteristics in cities of similar size.

To evaluate the possibility of estimating trip patterns of a city in a standard metropolitan statistical area, data were obrained and analyzed from fourteen such cities that had completed a transportation study. This study was restricted to cities with a statistical area population of less than one million.

For each of the fourteen study cities there were five basic areas, the central business district, the 1960 city area, the 1960 urbanized area, the 1960 standard metropolitan statistical area, and the transportation study area. The organization that performed each transportation study delimited the central business district and the entire trnasportation study area. In all cases the latter area was larger than the city area and smaller than the standard metropolitan statistical area.

In all cases the 1960 standard metropolitan statistical area contained the largest population. The populations for four of the basic areas for the study cities are listed in Table 2 .

In the conduct of this research, data used were obtained from the 1960 Census and from the fourteen transportation studies. Much of the data from the transportation studies used "dwelling unit" as defined by the 1950 Census as a basic unit. The data from the 1960 Census used "housing unit" as the basic unit. The main difference between these units was in the treatment of one-room quarters and this had relatively little effect on comparibility of the data for large areas.

In addition to the many variables that were obtained from the
Census and the transportation studies, many interactions were used in
evolving the various models. Interaction is the differential response
of one factor in combination with varying levels of a second factor
applied simultaneously, that is, interaction is an additional effect
due to the combined influence of two or more factors (3).

Total Vehicle Trips in a Study Area

Total vehicle trips in a study area are comprised of both the
internal and external one way movements. An internal trip has both
the origin and the destination within the confines of the delimited
study area and includes interzonal trips and intrazonal trips. An
external trip may have one or both ends of the trip outside the study
area and includes external-internal trips (called local trips in
this study) and through trips.

It would be erroneous to compare only the internal trips among
the fourteen locations because of the variability that exists in the
delimiting of the study area. It is obvious that the number of internal
trips will increase as the transportation area increases. The percent
of total vehicle trips that were internal trips ranged from 75.2 to 96.3.

The model evolved for this analysis was:

$$Y = + 142010 + 1.53441 \ X_1$$

$$- 8731.8 \ X_2 \tag{I}$$

where:

Y = total number of vehicle trips per day in a study area

X_1 = transportation study population

X_2 = percent of employed persons using public transportation
to work.

The amount of variability (R^2) explained by this model is 96.9 percent with a sample size of fourteen.

Effect of Study Population and Area

The ratios of external vehicle trips to total vehicle trips and local vehicle trips to internal vehicle trips vary with the size of the transportation study population and area, as shown in Figures 2 and 3. The lines shown are least square fits of data obtained from the fourteen study areas. It is easily seen that as the area increases, population increases with the effect that less trips are included in the external portion of the survey.

It was desired to know if the ratio of external trips and local trips to total trips could be estimated from the factors of population and area. The following models were evolved for this purpose.

$$Y = 0.4126 + 10^{-10} \left[0.0242\ X_1\ X_2^2 - 4644.2\ X_1 - 11351\ X_2^2 + 452.1\ (X_1/X_2)^2 - 1576380\ (X_1/X_2) \right] \qquad (II)$$

where:

    Y = ratio of external vehicle trips per day to total vehicle trips per day

    X_1 = transportation study population

    X_2 = transportation study area in square miles

and:

$$Y = +0.545 + 10^{-7} \left[-0.0267\ X_1\ X_2 - 17.4\ X_2^2 + 7.00\ (10^{-5})\ X_1\ X_2^2 + 0.656\ (X_1/X_2)^2 - 2774\ (X_1/X_2) \right] \qquad (III)$$

where:

    Y = ratio of local vehicle trips per day to internal vehicle trips per day

    X_1 = transportation study population

X_2 = transportation study area in square miles

The amounts of variability (R^2) explained by these models are 87.5 percent and 85.8 percent respectively with a sample size of fourteen.

Central Business District

The central business district is the largest traffic generator when considering vehicle trip ends per square mile as a measure of generation. For the central business districts and the next largest generators, the number of vehicle trip ends per square mile and the ratio of the two are shown in Table 3 for the fourteen cities.

Vehicle Trips to and from the Central Business District

The internal and external vehicle trips per day to and from the central business district consist of those trips that had either their origin or destination in that particular zone. These trips had an average of 73556 and ranged from 22855 in Huntsville to 119640 in New Orleans. The following model was evolved:

$$Y = -39570 + 0.04948 \ X_1 + 41335 \ X_2$$
$$-1443.9 \ X_3 + 1492.0 \ X_4 + 28.755 \ X_5 \qquad (IV)$$

where:

Y = vehicle trips to and from the central business district per day

X_1 = transportation study population

X_2 = area of the central business district in square miles

X_3 = percent of employed persons using public transportation to work

X_4 = percent of employed persons who had white collar occupations

X_5 = the interaction of the area of the central business

district by the transportation study population density.

The amount of variability (R^2) explained by this model is 94.4

percent with a sample size of fourteen.

For the fourteen locations there was an average of 13.36 percent

of the total vehicle trips that had an origin or desitnation in the

central business district and the range was from 7.80 percent in

Toledo to 20.27 percent in Tulsa. The relationship between the daily

vehicle trips to and from the central business district and the daily

total vehicle trips in a study area is shown in Figure 4.

Intrazonal Central Business District Vehicle Trips

The intrazonal central business district vehicle trips are those

movements that have both their origin and destination within that

particular delimited zone. The length of these trips are necessarily

very short due to the small area of the district, which was less than

one square mile for all the study locations.

These daily trips ranged from 1790 in Tucson to 13976 in New Orleans

and the following model was evolved:

$$Y = + 5790 + 6406.7\ X_1 + 0.8432\ X_2$$

$$- 1.18459\ X_3 - 0.00017\ X_4 + 0.01909\ X_5 \qquad (V)$$

where:

Y = intrazonal central business district trips per day

X_1 = area of the central business district in square miles

X_2 = transportation study population density

X_3 = median family income for the standard metropolitan

statistical area

X_4 = interaction of transportation study population by the

percent of employed persons using public transportation
to work

X_5 = interaction of the transportation study population by
the area of the central business district

The amount of variability (R^2) explained by this model is 98.5 percent
with a sample size of fourteen.

Study Zones

For the evolution of models for the number of vehicle trips per day
attracted to and generated by a zone, the number of vehicle trips per
day in both directions between a zone and the central business district,
and the number of interzonal vehicle trips per day, 75 study zones,
excluding the central business district, were chosen from thirteen
study cities. These were chosen on the basis of being representative
of the entire study area.

Analyses, therefore, were made on the vehicle trips attracted
to and generated by 75 zones, the vehicle trips in both directions
between those 75 zones and their respective central business districts,
and the interzonal vehicle trips within the cities. The resulting
number of interchanges was 269.

Zonal Vehicle Trips

For the 75 study zones a model was evolved for the total number
of vehicle trips per day attracted and generated by a zone. Total
trips consisted of internal trips, external trips, and intrazonal
trips. The following model was evolved:

$$Y = -7655 - 1326.4\ X_1 + 5.0602\ X_2$$
$$-0.01714\ X_3 + 43.416\ X_4$$
$$+7.2513\ X_5 + 2.07\ (10^{-6})\ X_6 \qquad (VI)$$

where:

Y = total number of vehicle trips per day attracted and generated by a zone

X_1 = straight line distance in miles from the centroid of the central business district to the centroid of the study zone

X_2 = number of passenger cars owned in the study zone

X_3 = population of the entire transportation study area

X_4 = transportation study area in square miles.

X_5 = transportation study density in persons per square mile

X_6 = three factor interaction of percent of population that are workers in a study zone by the number of people that are in the study zone by the number of cars that are in the study zone.

The amount of variability (R^2) explained by this model is 91.0 percent with a sample size of 75.

Zone-Central Business District Trips

A model for the number of vehicle trips per day in both directions between each of the 75 study zones and its respective central business district was evolved for the study cities. The following model was evolved:

$$Y = +498 + 0.46257\ X_1 - 96.700\ X_2 + 0.68270\ X_3 + 0.01331\ X_4$$

$$- 0.01967\ X_5 - 0.00300\ X_6 + 0.001767\ X_7 \qquad \text{(VII)}$$

where:

Y = number of vehicle trips per day in both directions between a zone and its central business district.

X_1 = population of the study zone.

X_2 = straight line distance in miles from the centroid of the central business district to the centroid of the study zone.

X_3 = number of passenger cars owned in the study zone.

X_4 = two factor interaction of percent of population that are workers in the study zone by the number of people that are in the study zone.

X_5 = two factor interaction of percent of employed persons who had white collar occupations for the standard metropolitan statistical area by the population of the study zone.

X_6 = three factor interaction of the straight line distance in miles from the centroid of the central business district to the centroid of the study zone by the percent of population that are workers in the study zone by the population of the study zone.

X_7 = three factor interaction of the straight line distance in miles from the centroid of the central business district to the centroid of the study zone by the percent of employed persons who had white collar occupations for the standard metropolitan statistical area by the population of the study zone.

The amount of variability (R^2) explained by this model is 91.7 percent with a sample size of 75.

Some investigators have related the independent variable of the above model, the number of vehicle trips per day between a zone and the central business district, to the total number of vehicle trips per day attracted and generated by the zone. This relationship for the 75 zones used in this research is shown in Figure 5. The R^2 for this relationship for the study zones was 75.4 percent while that for the evolved model was 91.7 percent.

Interzonal Vehicle Trips

A model for the number of vehicle trips per day in both directions for the zonal interchanges between the non-CBD zones in the study cities was evolved. The following model was evolved:

$$
\begin{aligned}
Y = \ & 796.2 - 0.1084\ X_1 - 0.04275\ X_2 - 133.7\ X_3 - 6.223\ X_4 \\
& + 15.29(10^{-4})\ X_5 + 20.84(10^{-4})\ X_6 - 0.7401(10^{-2})\ X_7 \\
& + 0.1018(10^{-4})\ X_8 - 0.5256(10^{-5})\ X_9 + 0.7234(10^{-3})\ X_{10} \\
& + 52.37(10^{-6})\ X_{11} + 1.262\ X_{12} - 11.10(10^{-10})\ X_{13} - 3.564(10^{-14})\ X_{14} \\
& - 8.876(10^{-10})\ X_{15} - 0.3867(10^{-11})\ X_{16} + 0.1507(10^{-6})\ X_{17} \\
& - 0.1886(10^{-6})\ X_{18} + 1.443\ X_{19} - 0.1514\ X_{20} - 232.1\ X_{21} \quad \text{(VIII)}
\end{aligned}
$$

where:

Y = number of vehicle trips per day in both directions for zonal interchanges between non-CBD zones.

X_1 = number of cars owned in the smaller populated zone.

X_2 = number of cars owned in the larger populated zone.

X_3 = distance in miles between the centroids of the two zones.

X_4 = angle in degrees between centroid of zone i and centroid
of zone j with the vertex at the centroid of the central
business district.

X_5 = two factor interaction of the population of the smaller
populated zone by the percent of population under 34 years
that are enrolled in school for that zone. This is a
measure of the school enrollment for that zone.

X_6 = two factor interaction of the population of the smaller
populated zone by the percent of workers in that zone.
This is a measure of the number of workers in that zone.

X_7 = two factor interaction of the population of the smaller
populated zone by the straight line distance in miles
between the centroids of the two zones.

X_8 = two factor interaction of the population of the larger
populated zone by the percent of population under 34 years
that are enrolled in school for that zone. This is a
measure of the school enrollment for that zone.

X_9 = two factor interaction of the population of the larger
populated zone by the percent of workers in that zone.
This is a measure of the number of workers in that zone.

X_{10} = two factor interaction of the population of the larger
populated zone by the straight line distance in miles
between the centroids of the two zones.

X_{11} = two factor interaction of the number of passenger cars
owned in one zone by the number of passenger cars owned
in the other zone.

X_{12} = **two factor interaction of** the distance in miles between the centroids of the two zones by the angle in degrees between the two zones with the vertex at the central business district.

X_{13} = four factor interaction of population of a zone by percent of population under 34 years that are enrolled in shcool in that zone by population of the other zone by percent of population under 34 years that are enrolled in school of the other zone. This is a measure of the two factor interaction of school enrollment by school enrollment.

X_{14} = four factor interaction of population of a zone by median income of families in that zone by population of the other zone by median income of families in the other zone.

X_{15} = four factor interaction of population of a zone by percent of workers in that zone by population of the other zone by percent of workers in the other zone. This is a measure of the two factor interaction of workers by workers.

X_{16} = three factor interaction of population of a zone by population of the other zone by transportation study population.

X_{17} = **three factor interaction of** population of a zone by population of the other zone by percent using public transportation to work for the standard metropolitan statistical area.

X_{18} = three factor interaction of population of a zone by population of the other zone by the straight line distance

in miles between the centroids of the two zones.

X_{19} = three factor interaction of the straight line distances
in miles between the zone and the central business district,
between the other zone and the central business district
and between the two zones.

X_{20} = three factor interaction of the straight line distance
in miles from the centroid of the zone to the central
business district by the distance from the other zone to
the central business district by the angle in degrees
between the two zones with the vertex at the central
business district.

X_{21} = two factor interaction of the population of the smaller
zone by the percent of workers in that zone divided by
the two factor interaction of the population of the
larger zone by the percent of workers in that zone.
This is a measure of the ratio of workers between two
zones.

The amount of variability (R^2) explained by this model is 70.0
percent with a sample size of 269.

DESIGN HOUR TRAFFIC VOLUME

Since a transportation facility should operate efficiently most
of the time, the period of greatest interest is that of peak-hour
travel. A relationship, therefore, between average daily traffic and
peak-hour travel is desired.

The hourly variations in vehicle traffic volumes for sixteen of
the daily hours were available for seven of the fourteen study cities.

All of the locations were quite similar in pattern as is shown in Figure 6. For all cities the evening peak was the highest and it occurred between 4 p.m. and 6 p.m. The mean for this primary peak was 8.8 percent with a range from 8.3 to 9.3 percent. The secondary peak, which occurred between 7 a.m. and 9 a.m. for all locations, had a mean of 7.1 percent and a range from 6.0 to 8.4 percent.

The hourly traffic variation for all large urban areas may be quite similar, as Figure 7, which shows the hourly average of the seven cities (all of which had less than one million population), does not indicate a significant variation for the Detroit area, which has approximately four million people. The evening peaks are quite similar, even though the peak hour extends over a longer period of time in Detroit, 3 to 6 p.m.

Thus it appears that the average peak hour traffic volume for a facility could be estimated quite reliably from the average daily traffic volume of that facility by the use of the mean percentage of 8.8 for the peak hour.

The average peak hour volume, however, is not normally the one used for design purposes. The peak-hour volume representative of the thirtieth highest hourly volume of the year is the generally accepted criterion. Exception may be necessary in those areas or locations where concentrated recreational or other travel during some seasons of the year results in a distribution of traffic volume of such nature that a sufficient number of hourly volumes are so much greater than the thirtieth highest hourly volume that they cannot be tolerated and a higher value must be considered in design (4).
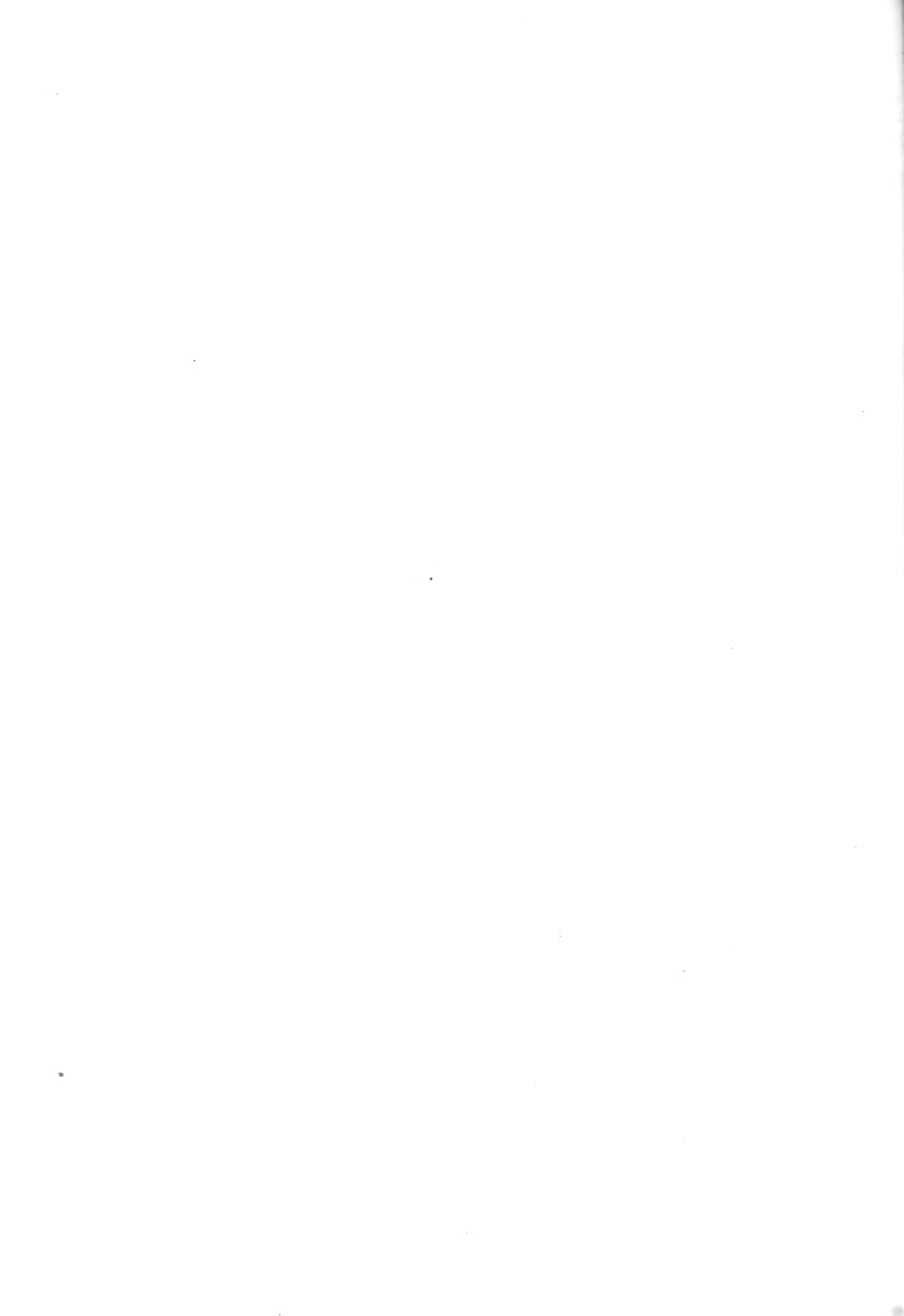
The typical daily and monthly variations in addition to the hourly variations were available for Chattanooga, Nashville, New Orleans, and Tucson. These two variations are illustrated in Figures 8 and 9. For all four cities the lowest and highest daily variations occurred on Sunday and Friday respectively, but there was a wide range of values. The two Tennessee cities had the lowest monthly variations in February and the highest in June, while Tucson had the highest in February and lowest in July. New Orleans had a peak in January and the lowest percent occurred in March.

Using the hourly, daily, and monthly variations in these four cities, a computer program was written for the estimation of the percent of daily traffic which traveled during 2016 hours of the year in each of the four cities. The equation for this program was

$$C_{ijk} = H_i \times D_j \times M_k$$

Where:

C_{ijk} = percent of hourly traffic divided by the annual average daily traffic for the ith hour of the jth day in the kth month.

H_i = percent of hourly traffic for the ith hour,

$i = 1, 2, \ldots 24.$

D_j = daily factor for the jth day, obtained by dividing the volume of traffic on the jth day by the average daily volume,

$j = 1, 2, \ldots 7.$

M_k = monthly factor for the kth month, obtained by dividing the volume of traffic in the kth month by the average

monthly volume,

$k = 1, 2, \ldots 12.$

Except for a few special events which might have had unusually high volumes of traffic in these cities, the values obtained from the equation are representative of all hours of the year because the weekly variations in traffic within one month (which were not included) are small and generally not enumerated in a volume count program.

The analysis made on the data from the four cities is summarized in Table 4, which also shows the average values from the Highway Capacity Manual for 38 locations in eight cities (5). It is interesting to note the small difference in percentages for the highest 100 hours in each of the four cities. Close agreement between their means and the means from the Manual exists with the largest difference occurring at the highest hour. The values from the four cities are also in agreement with the suggested values of the American Association of State Highway Officials, which are 7 to 18 percent of the average daily traffic with a mean of 11 percent. Table 4 also verifies the characteristic that the fluctuation in peak-hour volumes from day-to-day in any one year is relatively small on urban arterials (4). From these observations, a value of ten percent of the average daily traffic should be a good estimate for the design hour volume in an urban area within a standard metropolitan statistical area.

This relation between the design hour volume (30th highest hour) and average daily traffic on urban facilities is lower than on rural facilities, as is illustrated in Figure 10, which shows the curves for the mean of the study cities, the average for 167 main rural highway

locations in 48 states (6), and an urban through route from the Connecticut
State Highway Department (7).

SOME IMPORTANT VARIATIONS IN DESIGN HOUR VOLUMES

The volume of traffic during the design hour is that volume in the
design year for which sufficient capacity should be provided. The
capacities required for a freeway and its interchange ramps, however,
are vitally affected by the number of trucks in the design hour volume
and in the distribution of the direction of travel during the design
hour.

Average daily traffic volume consists of passenger cars and trucks.
Light delivery trucks, such as panels and pickups are normally considered
as passenger cars. Trucks include all buses, single-unit trucks, and
truck combinations, that is, vehicles with dual tires on the rear axle
or those having 9000 pounds or greater gross vehicle weight rating.
Truck trips during the design hour often are considered as a percentage
of total vehicular traffic and are referred to by the letter T (4).

Average daily truck trips averaged 16.20 percent of the total
vehicular trips for the fourteen study cities and ranged from 7.39
percent in Huntsville to 25.98 percent in New Orleans. A regression
analysis relating truck trips to total vehicle trips for all the
cities was made and the relation is given below.

$$Y = -19900.5 + 0.20631 \ X \qquad\qquad (IX)$$

where:

   Y = truck trips per day in the study area

   X = total vehicle trips per day in the study area

The relationship between truck trips and total vehicle trips is shown in Figure 11.

The hourly variations in truck volumes varied considerably from the hourly variations in total vehicular volumes for the four cities for which these variations were available as is evidenced from Figure 12. None of the four cities had the truck peak hours occurring from 4 p.m. to 6 p.m., which were the peak hours for total vehicle trips, but had peaks beginning at 8 a.m., 9 a.m., 10 a.m., and 2 p.m. The mean percent of trucks traveling during the peak hour of total travel (4 - 6 p.m.) was 7.2 percent of total truck trips.

A value for the percent of total vehicle trips that are truck trips at the design hour may be estimated from the equation below.

$$T = \frac{K_T \; ADT \; Trucks}{K \; ADT} \times 100$$

where:

T = percent of total vehicles that are trucks at the design hour.

K_T = percent of truck trips at the design hour.

K = percent of total trips at the design hour.

ADT_{Trucks} = average daily traffic of trucks at the design year.

ADT = average daily traffic of vehicles at the design year.

K_T was found to have a mean value of 7.2 for the four cities of this study which had this information available. A good value for K was previously shown to be 10.0 percent. The use of these values will permit an estimation of T which should be adequate for the determination of capacity requirements during the design hour.

The second factor previously mentioned as important in the determina-

tion of capacity requirements was directional distribution of traffic
volume during the design hour. Considerable research on this factor
has indicated that rarely is traffic evenly distributed during the
design hour, although this situation may be approached in and near
the central business area (5). The amount of traffic flowing in
the direction of heavier movement in urban areas has normally been
found to range from 55 percent near the central business district
to 60 percent in intermediate areas to 65 percent in outlying areas (5).

Conclusions

These conclusions are applicable to major urban areas of standard
metropolitan statistical areas of less than one million population.

A. The following travel pattern elements or characteristics
can be reliably estimated for a transportation study area by
use of the indicated models developed in this research.

1. The total number of vehicle trips per day - Model I.

2. The ratio of external vehicle trips per day to total
vehicle trips per day - Model II.

3. The ratio of local vehicle trips per day to internal
vehicle trips per day - Model III.

4. The number of vehicle trips per day to and from the central
business district - Model IV.

5. The number of intrazonal central business district vehicle
trips per day - Model V.

6. The total number of vehicle trips per day attracted and
generated by each zone - Model VI.

7. The number of vehicle trips per day between a zone and the

central business district - Model VII.

8. The number of interzonal vehicle trips per day between
   two zones, excluding the central business district - Model VIII.

B. The central business district is the largest generator of trips
   within the transportation study area.

C. The number of truck trips per day in a transportation study
   area can be reliably estimated by the use of Model IX.

D. A good estimate of the design hour volume (30th highest hour)
   is ten (10) percent of the average daily traffic volume.

Models for trip prediction will not supplant all field studies
in urban areas but models are a tool that can assist in the understanding
of urban transportation problems. It is imperative that continuing
studies of travel characteristics be made so that travel patterns in
urban areas can be thoroughly understood by the transportation planner.

List of References

1. Goldfield, Edwin D. "County and City Data Book 1962," U. S. Department of Commerce, U. S. Government Printing Office, 1962.

2. Anderson, Virgil L., "Statistical Analyses," Purdue University, Lafayette, Indiana, 1962.

3. Ostle, Bernard, "Statistics in Research," Iowa State University Press, Ames, Iowa, 1963.

4. "A Policy on Arterial Highways in Urban Areas," American Association of State Highway Official, 1957.

5. "Highway Capacity Manual," Committee on Highway Capacity, Highway Research Board, U. S. Government Printing Office, 1950.

6. "A Policy on Geometric Design of Rural Highways," American Association of State Highway Officials, 1954.

7. Matson, T. M., Smith, W. S., and Hurd, F. W., "Traffic Engineering," McGraw-Hill Book Company, Inc., 1955.

TABLE 1

CLASSIFICATION OF STANDARD METROPOLITAN STATISTICAL AREAS

Population Classification	No. of Areas 1960 Census	Percent of Total	Cumulative Percentage
50,000 - 100,000	22	10.38	10.38
100,000 - 500,000	137	64.62	75.00
500,000 - 1 million	39	13.68	88.68
Over 1 million	24	11.32	100.00
Total	212	100.00	

TABLE 2

POPULATIONS OF FOURTEEN STUDY CITIES

City	Transportation Study	1960 SMSA	1960 Urbanized Area	1960 City
Charlotte	202262	272111	209551	201564
Chattanooga	241709	283169	205143	130009
Dayton	425000	694623	501664	262332
Denver	816700	929383	803624	493837
El Paso	268968	314070	277128	276687
Huntsville	73260	117348	74970	72365
Nashville	357585	399743	346729	170874
New Orleans	855551	868480	845237	627525
Omaha	296449	457873	389881	301598
San Antonio	586586	687151	641965	587718
Springfield	99020	131440	90157	82723
Toledo	405000	456931	438283	318003
Tucson	242550	265660	227433	212892
Tulsa	240419	418974	298922	261685
Range	73260-855551	117348-929383	74970-845237	72365-627525

TABLE 3

TRAFFIC GENERATING CHARACTERISTICS
OF THE CENTRAL BUSINESS DISTRICT

City	Trips Ends per mi^2	Largest Generator Outside CBD Trip Ends per mi^2	Ratio of CBD to Next Largest Generator
Charlotte	142055	18866	7.53
Dayton	207344	101539	2.04
Denver	250269	39196	6.39
El Paso	355974	30349	11.73
Huntsville	201058	14990	13.41
New Orleans	213901	44730	4.78
Omaha	203101	48438	4.19
San Antonio	298055	34471	8.65
Springfield	312319	43222	7.23
Toledo	261387	17498	14.94
Tucson	229446	53747	4.27
Tulsa	241870	86236	2.80
Range	142055-355974	14990-101539	2.04-14.94

TABLE 4

HOURLY PERCENT OF AVERAGE DAILY TRAFFIC

	Highest	10th	20th	30th	50th	100th	180th	Lowest
Chattanooga	10.0	9.8	9.5	9.4	9.2	9.0	8.7	0.3
Nashville	10.6	10.5	10.3	10.1	9.9	9.7	9.4	0.5
New Orleans	10.1	9.8	9.6	9.5	9.5	9.3	9.1	0.3
Tucson	9.8	9.8	9.7	9.3	9.1	8.9	8.6	0.3
Mean	10.1	10.0	9.8	9.6	9.4	9.2	9.0	0.4
Highway Capacity Manual[1]	12.4	10.9	10.5	10.2	9.5	N.A.[2]	N.A.	N.A.

1 - Average for 38 locations in 8 cities

2 - N.A. - Not Available
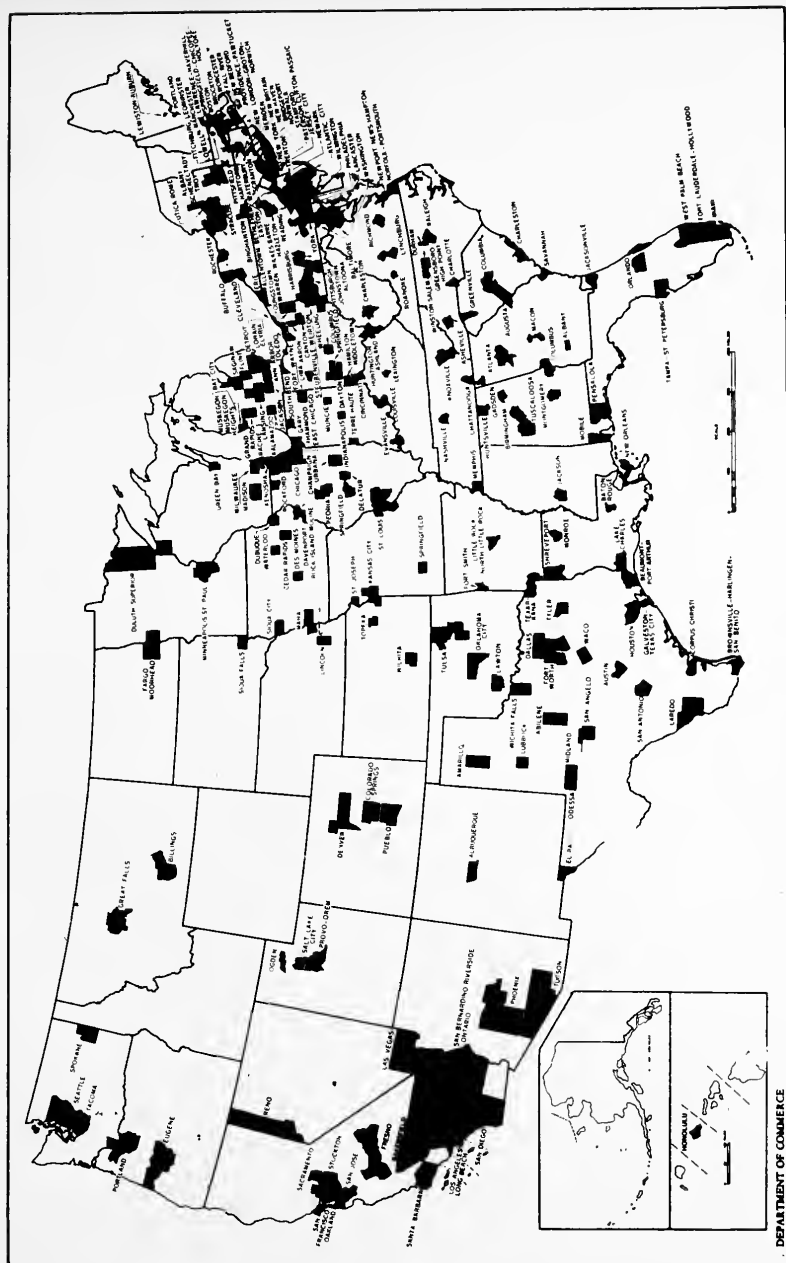
FIG. I   STANDARD METROPOLITAN STATISTICAL AREAS : 1960

FIG. 2 RELATION OF EXTERNAL TRIPS AND TRANSPORTATION STUDY POPULATION

LEGEND:

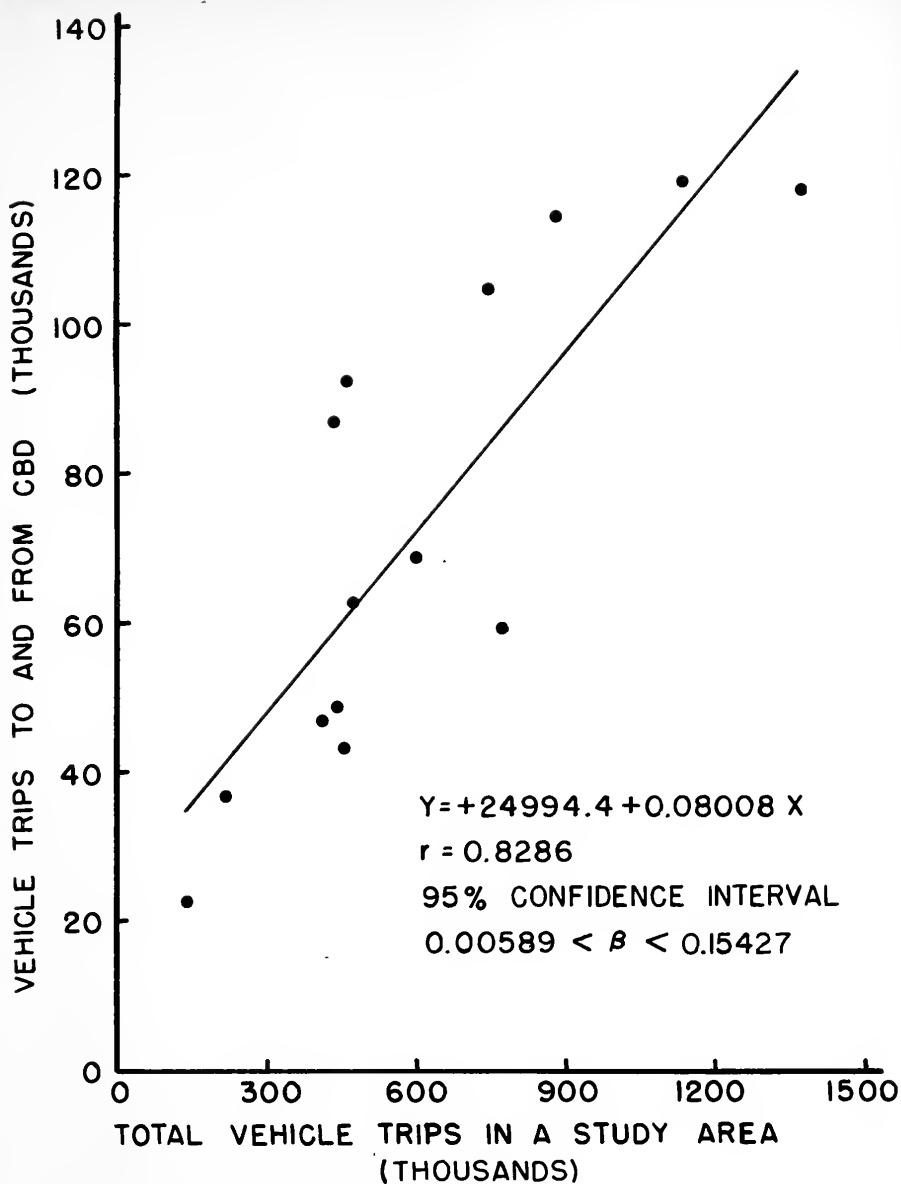RATIO OF EXTERNAL VEHICLE TRIPS TO TOTAL VEHICLE TRIPS ———

RATIO OF EXTERNAL VEHICLE TRIPS ie. LOCAL TRIPS TO INTERNAL TRIPS — — —

TRANSPORTATION STUDY AREA – Mi.²

RATIO

FIG.3 RELATION OF EXTERNAL TRIPS AND TRANSPORTATION STUDY AREA

$$Y = +24994.4 + 0.08008 X$$
$$r = 0.8286$$
95% CONFIDENCE INTERVAL
$$0.00589 < \beta < 0.15427$$
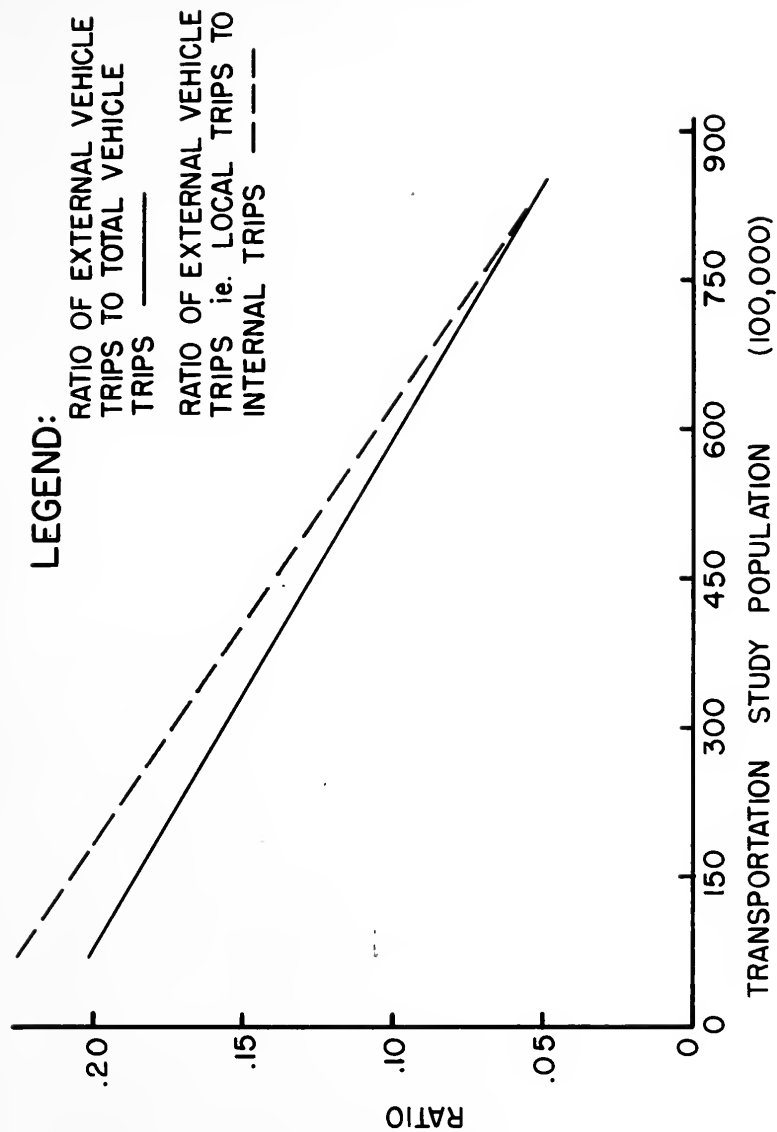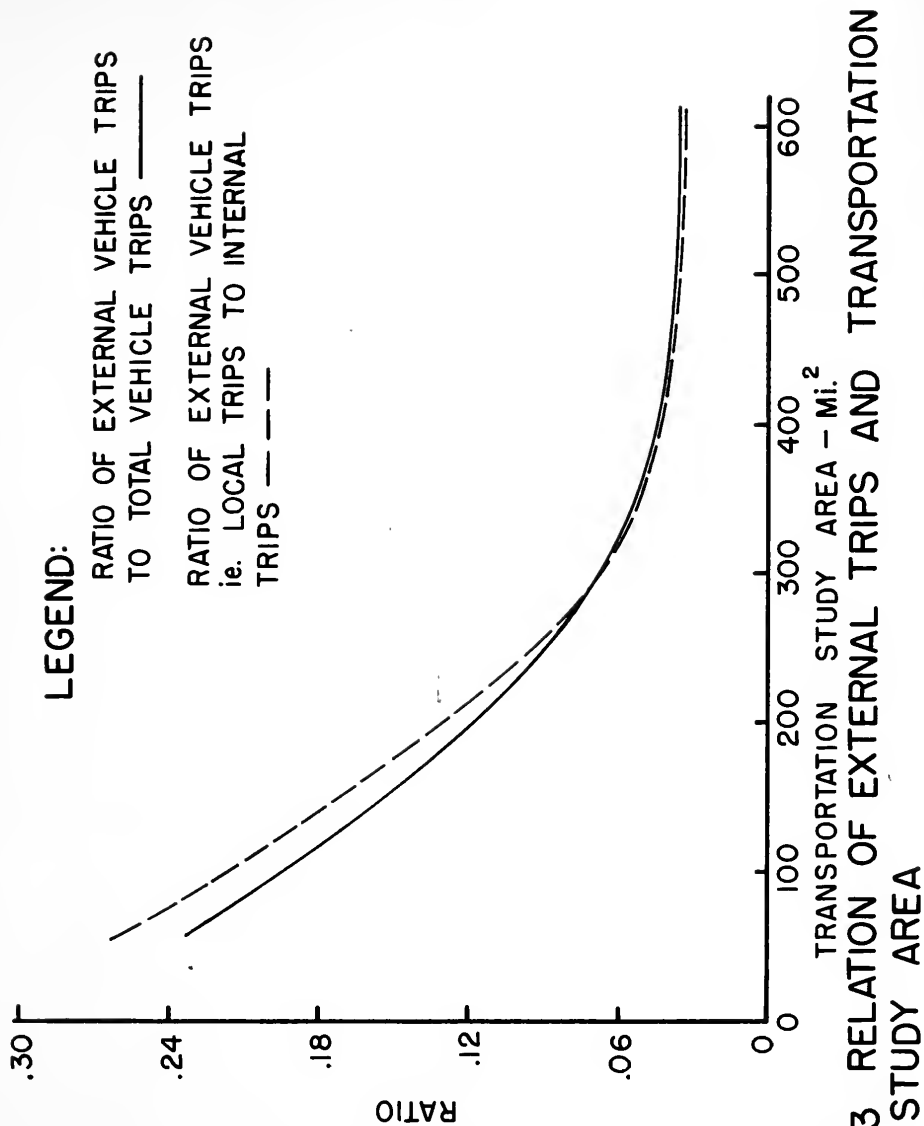
FIG. 4 RELATION BETWEEN VEHICLE TRIPS
TO AND FROM CBD AND TOTAL VEHICLE TRIPS
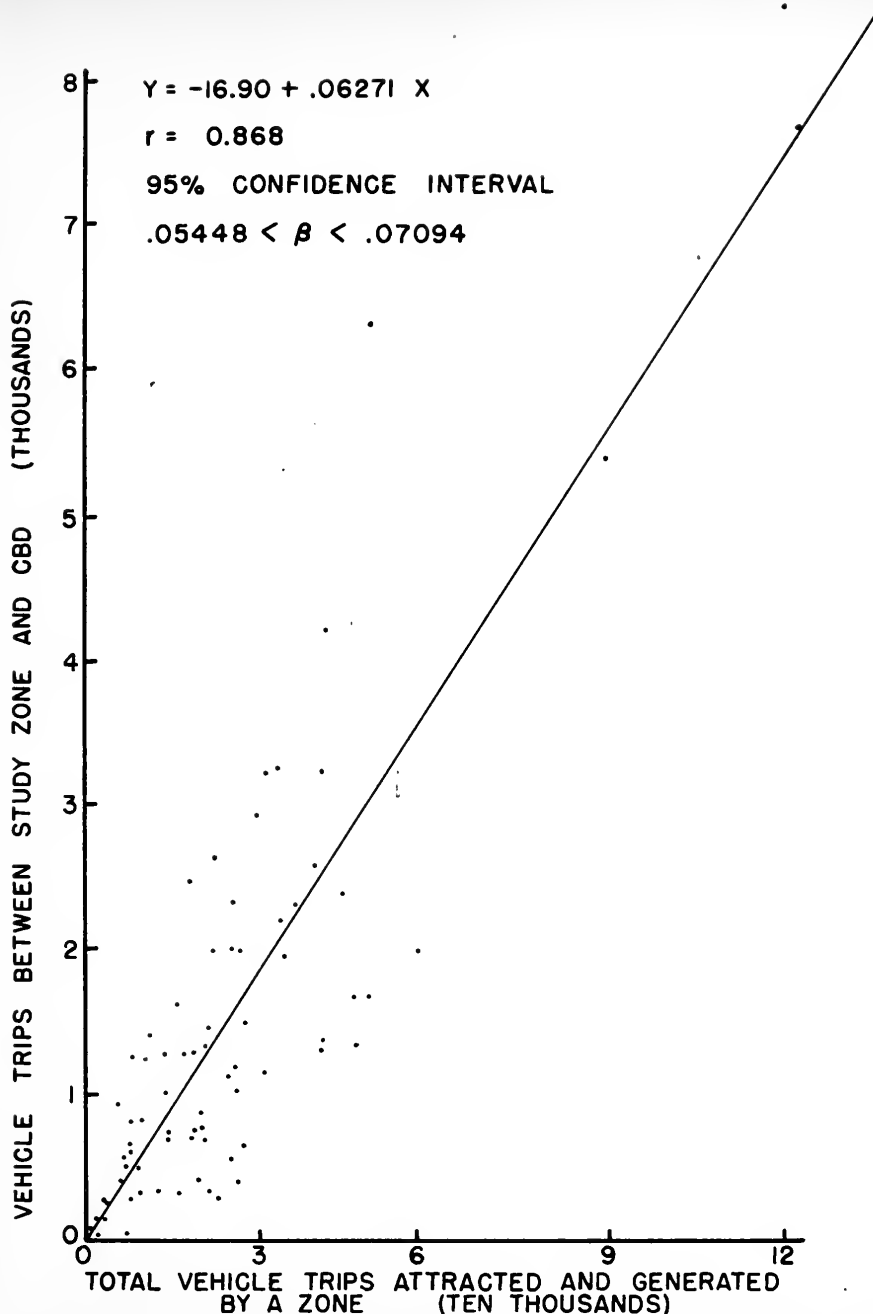
FIG. 5 RELATION BETWEEN CBD TRIPS AND TOTAL TRIPS FOR STUDY ZONES

LEGEND:
CHARLOTTE
CHATTANOOGA
DAYTON
NASHVILLE
NEW ORLEANS
SPRINGFIELD
TUCSON

PERCENT OF TOTAL VEHICLE TRAFFIC

TIME FOR HOUR PERIODS
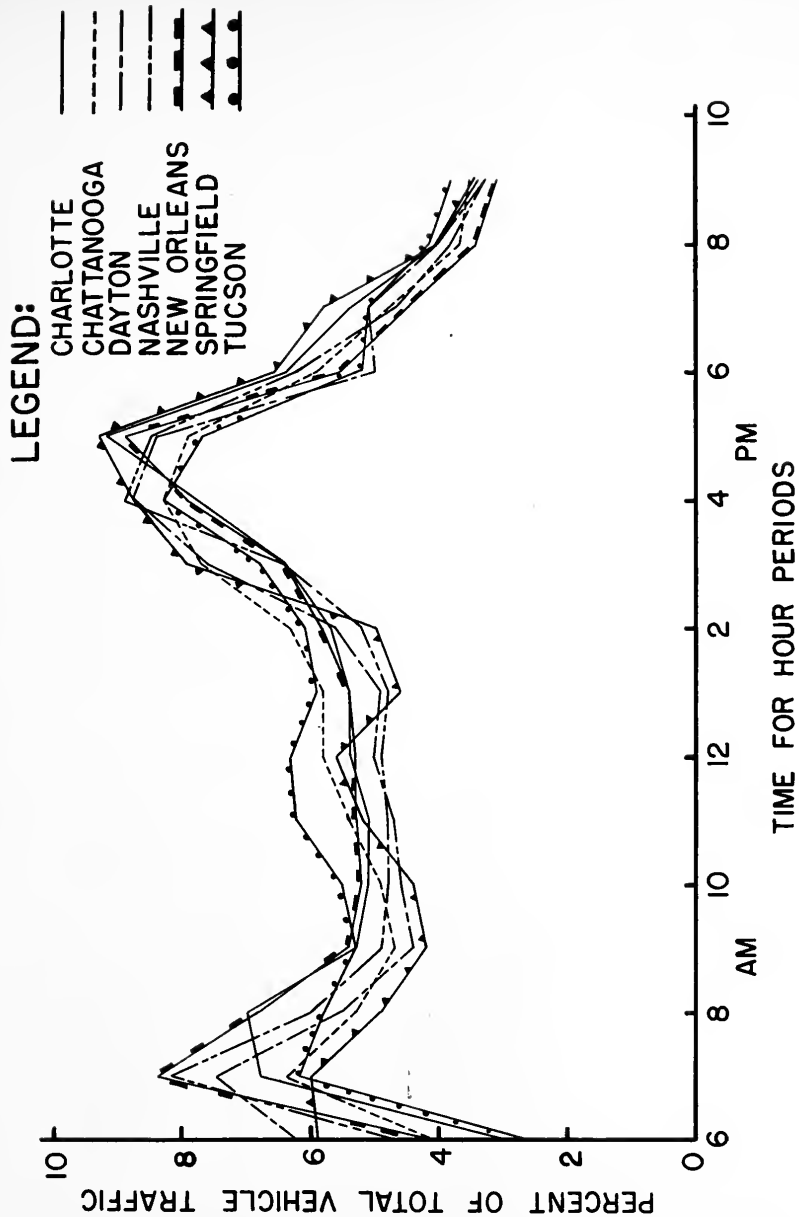
FIG. 6 HOURLY VARIATIONS IN TRAFFIC FLOW FOR 7 CITIES
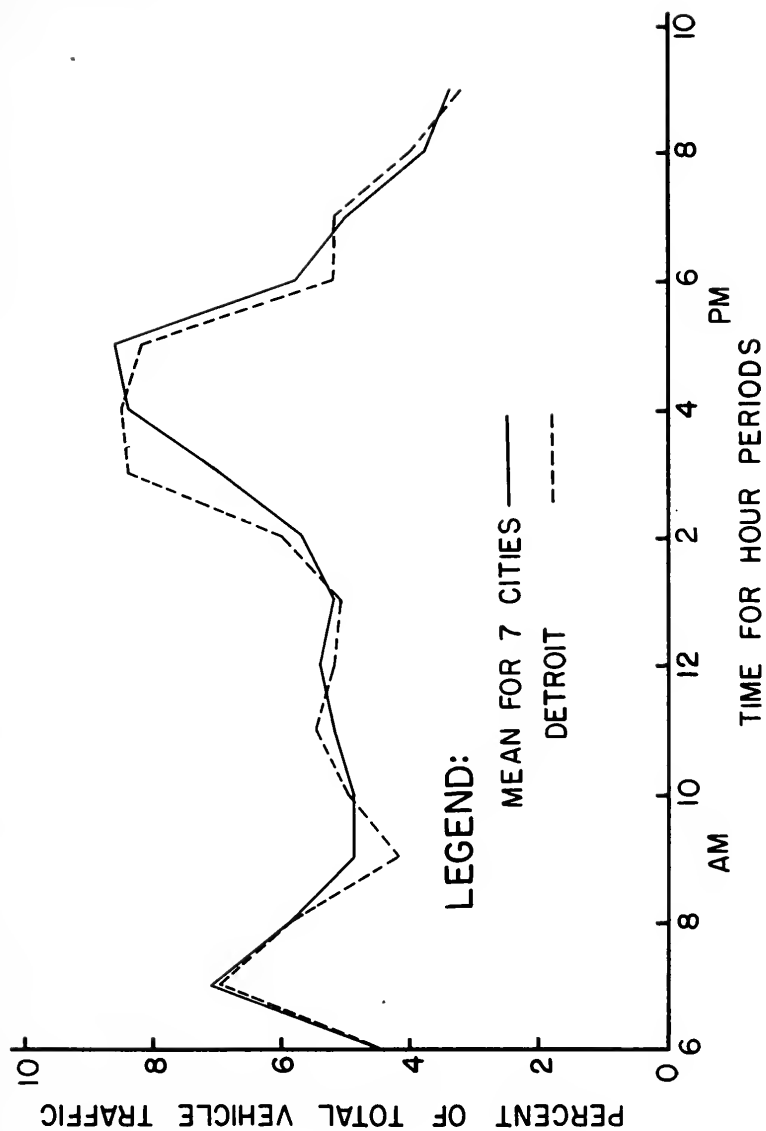
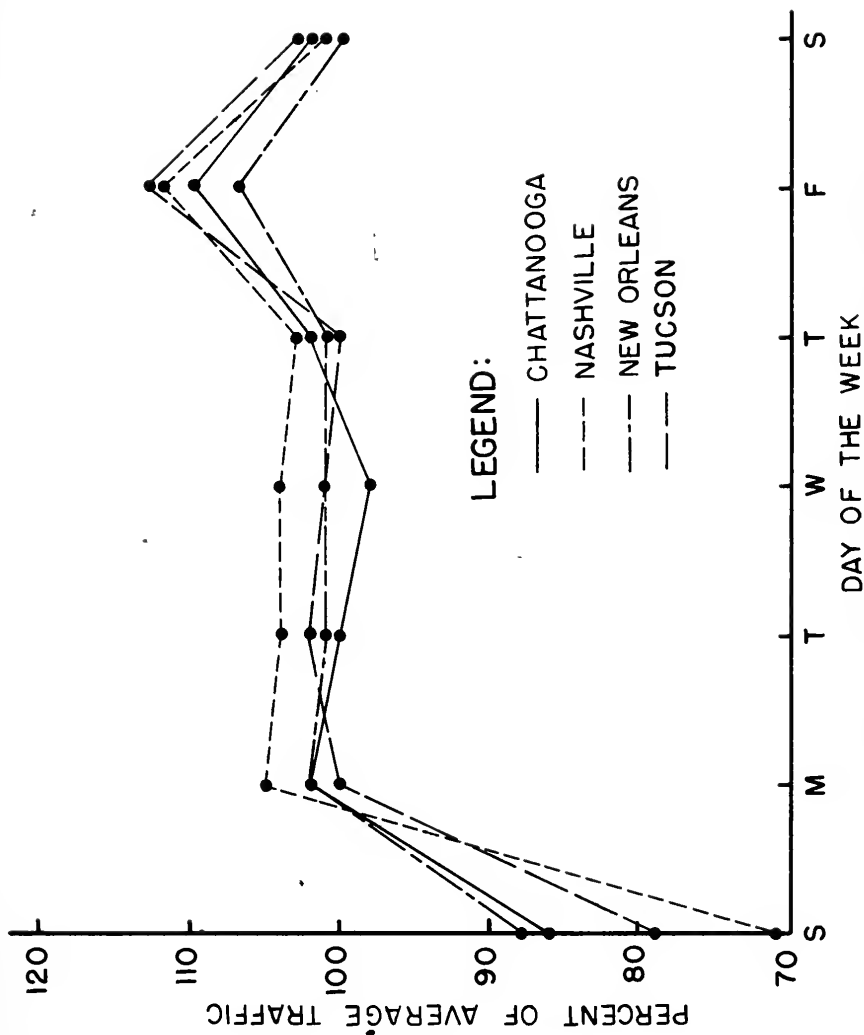FIG. 7 COMPARISON OF MEAN HOURLY VARIATIONS IN
TRAFFIC FLOW WITH DETROIT
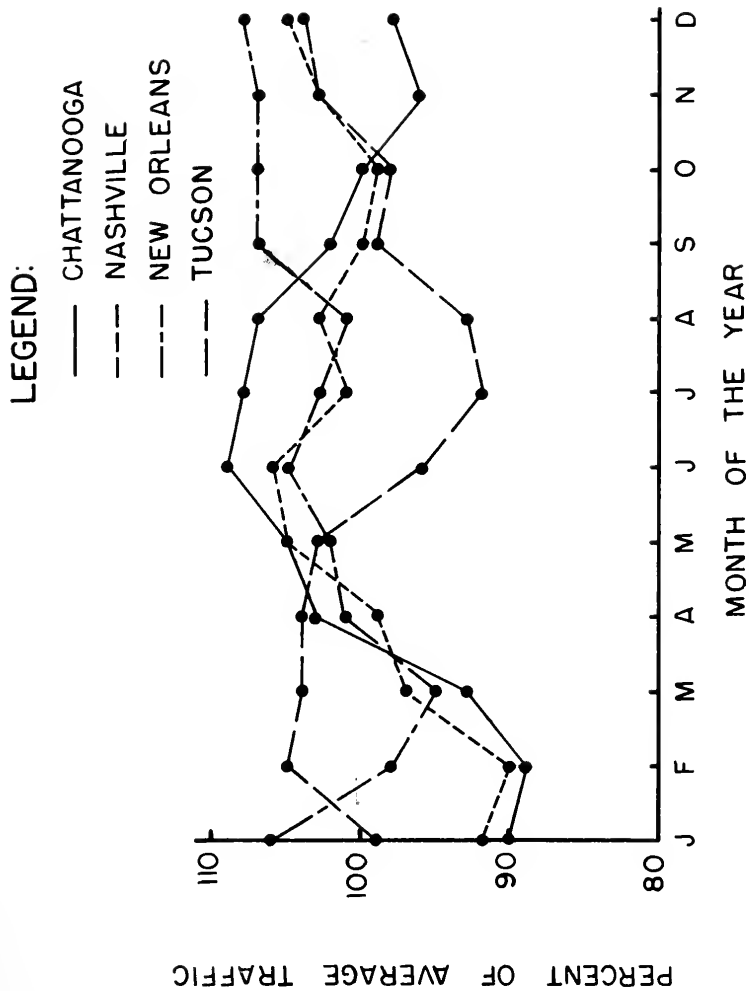
FIG. 8   DAILY VARIATIONS IN TRAFFIC FLOW

LEGEND:
——— CHATTANOOGA
– – – NASHVILLE
–·–·– NEW ORLEANS
——— TUCSON

PERCENT OF AVERAGE TRAFFIC

DAY OF THE WEEK

LEGEND:

—— CHATTANOOGA

– – – NASHVILLE

–·–·– NEW ORLEANS

– – – TUCSON

PERCENT OF AVERAGE TRAFFIC

MONTH OF THE YEAR

FIG. 9   MONTHLY VARIATIONS IN TRAFFIC FLOW
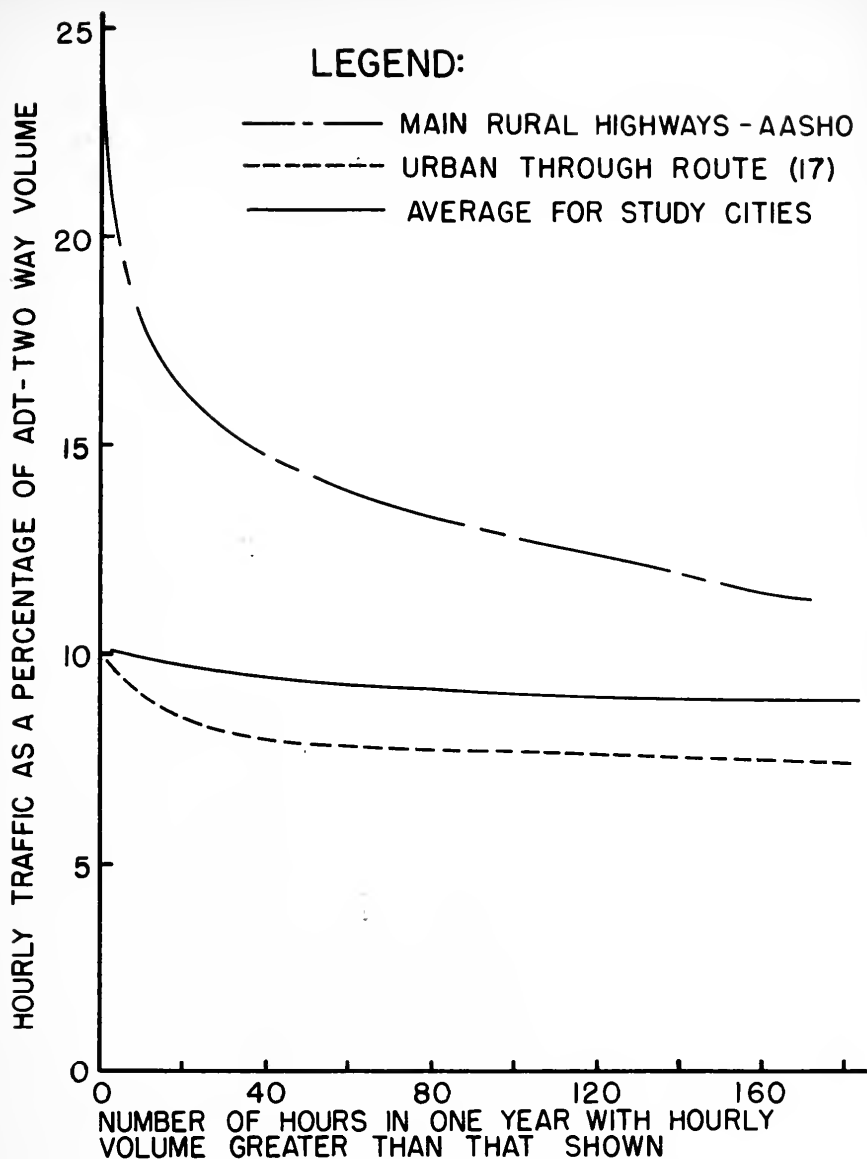
FIG.10 RELATION BETWEEN PEAK-HOUR AND
AVERAGE DAILY TRAFFIC VOLUMES

Y = -19900.5 + .20631 X

SIMPLE CORRELATION COEFFICIENT = .89780

95% CONFIDENCE INTERVAL

.14264 < β < .26998

TRUCK TRIPS (HUNDRED THOUSANDS)

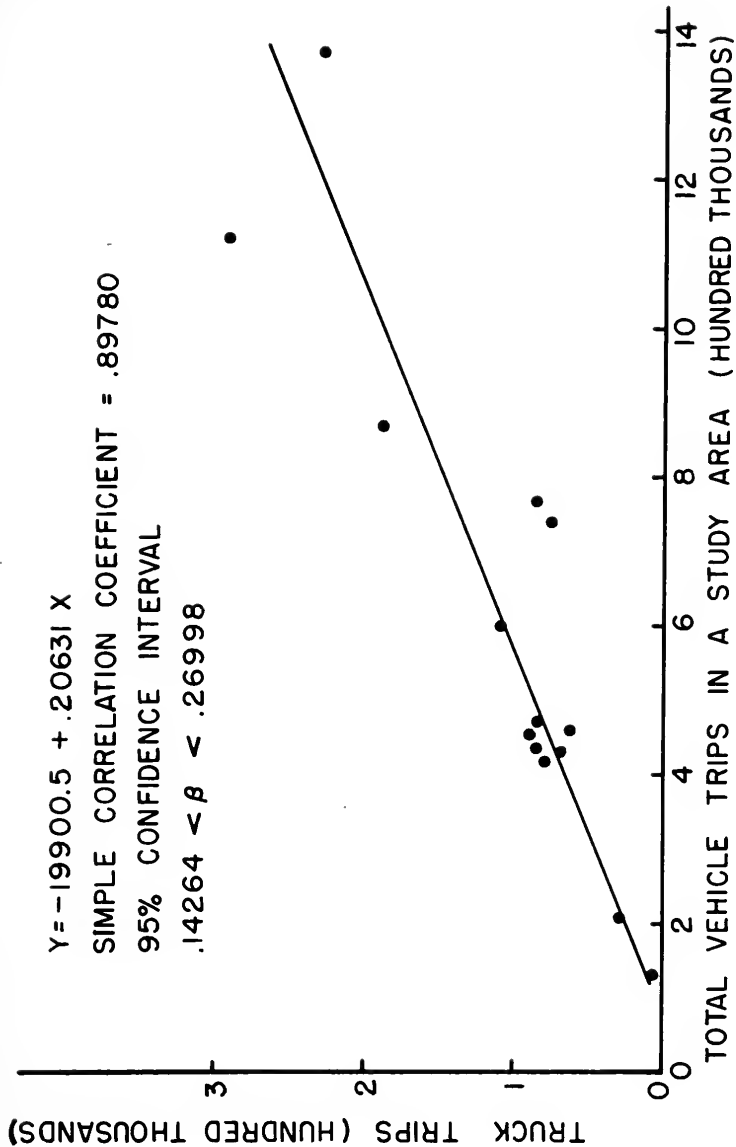TOTAL VEHICLE TRIPS IN A STUDY AREA (HUNDRED THOUSANDS)
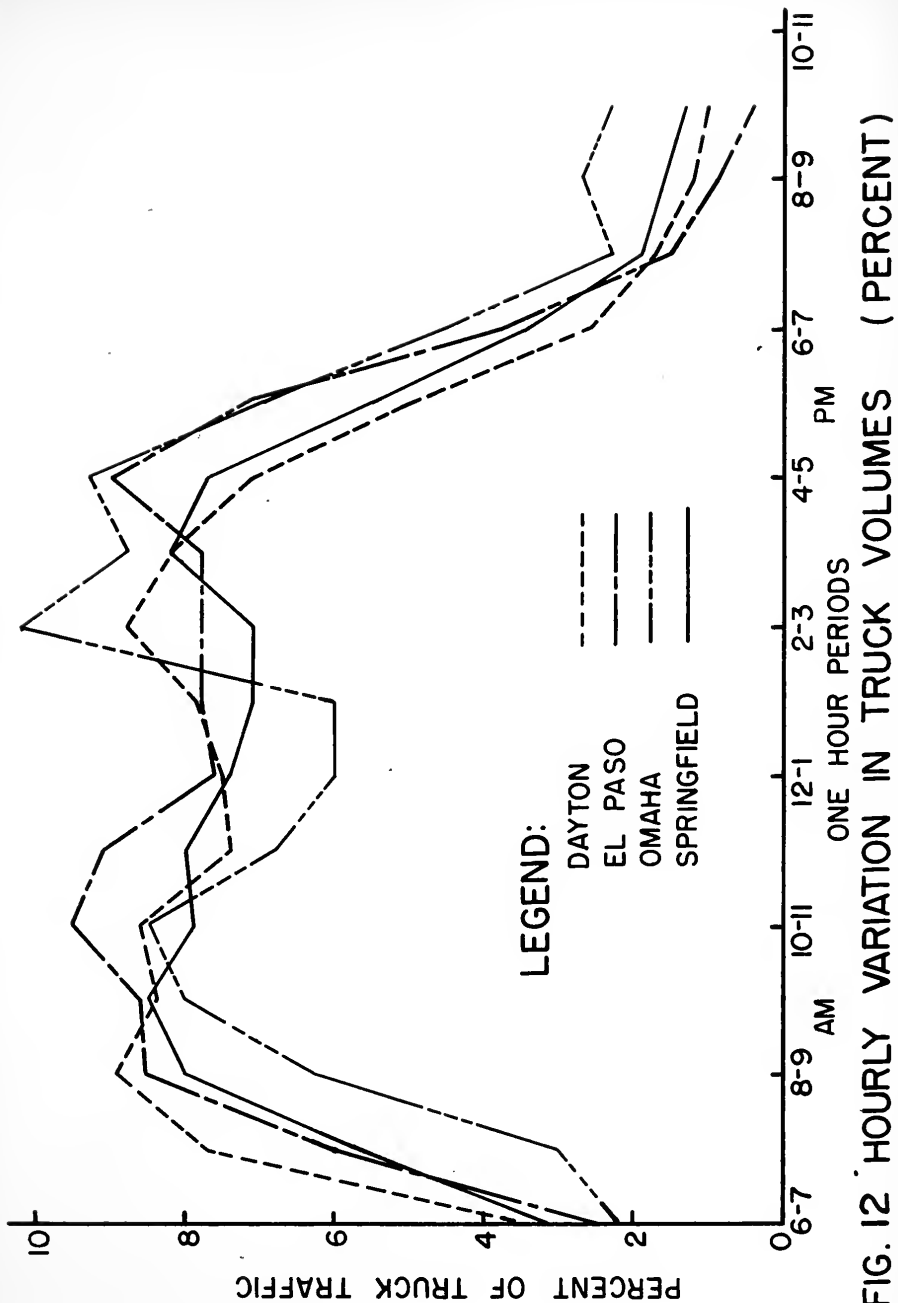
FIG. II RELATION BETWEEN TRUCK TRIPS AND TOTAL VEHICLE TRIPS

FIG. 12 HOURLY VARIATION IN TRUCK VOLUMES (PERCENT)